Aeropod-protected infrared camera provides dynamic rocket motor images

Leo Gauthier, Michael Mattix, Linda Howser, and Daniel Prendergast

A rugged, miniature, uncooled IR camera provides images while attached to an active rocket booster.

Thermal imaging systems indirectly observe radiating objects with infrared cameras. By using the longer thermal wavelengths that practically all objects emit, these cameras form the basis of many applications requiring radiometric imaging without external illumination.

Until the late 1990s, infrared cameras were large, expensive, and inefficient devices that did not perform well in severe environments. In fact, much of the power used by the original thermal imagers was used to drive complex optical scanning mechanisms and to reduce the noise floor of the detector rather than to power the sensor. In addition, their scanning mechanisms were susceptible to damage from shock and vibration.

Recently, however, uncooled infrared cameras based on arrays of bolometers (thermal detectors that measure incident electromagnetic radiation) have reduced the power requirements, size, and environmental vulnerability of thermal imaging systems. The smallest infrared cameras now fit in the palm of a hand and operate reliably in demanding environments on less than 2W of power. These advances have extended the range of applications to include in-the-dark surveillance, preventative maintenance, weatherproofing of structures, and pollution studies.

Another important application for infrared cameras is the measurement of the dynamics of rocket booster motors, including solid-fuel, that lift payloads above Earth’s atmosphere. In the past, the performance and characteristics of such motors were difficult to assess. Ground tests measured some aspects of the system but often failed to capture the effects from decreasing air pressure with increasing altitude. Infrared cameras on the ground and other long-range sensors observed rocket motors in flight but performance suffered due to atmospheric distortions and low signal-to-noise ratios. Added to these problems, installing sensing devices—especially infrared cameras—on the outside of rocket motors was impractical due to excessive shock, vibration, and thermal environments.

Our multidisciplinary team from The Johns Hopkins University/Applied Physics Laboratory (JHU/APL) developed a protective aerothermal pod, called an aeropod, to protect cameras on the outside of the rocket booster. The aeropods isolate the cameras from the worst mechanical stresses, keep hot gases on the outside of the rocket from coming into contact with the cameras, and provide the electrical interface between the cameras and the vehicle.

Thermoteknix Systems Ltd., a British manufacturer of infrared systems, provided a sealed, ruggedized Miric® TB2-30 camera capable of working over the full pressure range of the rocket’s flight: from one atmosphere at liftoff down to exoatmospheric levels outside the Earth’s atmosphere. One reason that the Miric TB2-30 camera was selected was because it had demonstrated excellent...
performance in the high-vibration environment of racing cars. This ability convinced the JHU/APL team that the camera could be isolated from the booster rocket’s dynamics so that acceptable vibration levels could be maintained and thus allow the camera to survive the flight. In addition, dry argon gas inside the camera ensured that the internal optics remained free of condensation.

Figure 1 shows two aeropods attached to the outside of the rocket booster just above a dark band— one positioned on the left and the other in the center. In this particular case, the infrared camera is located inside the center aeropod, approximately 10 m in front of the motor nozzle. Even though the aeropod protrudes from the rocket’s shell into the slipstream (the area behind the fast-moving rocket), it is designed to keep external heating from coming into contact with the camera itself.

During the rocket’s flight, the telemetered data was remotely monitored from the ground. Rapid surface heating of the aeropod’s exterior occurred as the vehicle traveled through the atmosphere. However, the camera stayed within its calibration window of 20°C to 40°C over the full flight sequence from launch to re-entry. The shock and vibration levels at the camera location were also quite severe. As the rocket motor burned, the hot gases emanating from the nozzle generated sizeable vibrations that were isolated from the camera by the design of the pod.

The camera successfully captured the plume dynamics and the ejection of motor debris throughout the flight sequence (Figure 2). Afterwards, our JHU/APL team extracted the radiometric data from the mission. Using the camera’s laboratory performance as its base, the team developed five distinct calibration steps to post-process the flight data. These calibration steps provide an accurate way to correct measurements for camera temperature variations, spectral responsivity, camera pointing and orientation, pixel response times, and measurement variations.

To validate the processing steps, the team developed a simulation program using MATLAB™ to simulate dynamic scenes from the mission. Post-processing algorithms using closed-loop error correction methodology validated the comparisons made between the post-processed and simulated data.

Technological improvements in infrared imaging technology such as reduced size, reduced power requirements, and improved ruggedness have allowed us to measure rocket motor performance with infrared cameras attached to rocket boosters from launch through re-entry into the Earth’s atmosphere. The dynamic radiometric measurements of the rocket motor required detailed camera characterization and additional calibration steps. Future efforts will refine these processing steps to account for the effects of camera motion and to measure more accurately the positions of objects of interest.

The authors would like to acknowledge the following: Eric Hedlund, director of Aegis Ballistic Missile Defense Test and Evaluation, for sponsoring the project; Joseph Mulé, JHU/APL project manager, for leading the project; Mark Harold, JHU/APL designer of the aerothermal pod; Charles Rodeffer, JHU/APL Sensor Payload Systems engineer; David Lohr, JHU/APL telemetry interface engineer; John O’Neil, Hasan Oguz, and Pete Green, JHU/APL chuff model scientists and data analysts; and Richard Salisbury, managing director of Thermoteknix Systems Ltd., and his team who provided the Miric TB2-30 camera.

Author Information

Leo Gauthier, Michael Mattix, Linda Howser, and Daniel Prendergast
JHU/APL
Laurel, Maryland

Mr. Leo Gauthier is a Senior Electrical Engineer in the Electro-Optical Systems Group of the Johns Hopkins University/Applied Physics Laboratory (JHU/APL). He has worked at APL since 1991 on a variety of projects with a focus on systems engineering, instrumentation and program development. He holds four patents in measurement technology. In addition, He has been a member of SPIE for several years and has published in SPIE proceedings.

Mr. Michael Mattix is a Senior Electrical Engineer in the Electro-Optics Group of the Johns Hopkins University/Applied Physics Laboratory (JHU/APL). He has been at JHU/APL since 1996 and works primarily with testing and data analysis of infrared seekers. In addition, He has participated in SPIE conferences and taken short courses through SPIE.

Ms. Linda Howser is a Senior Electrical Engineer in the Electro-Optics Group of the Johns Hopkins University/Applied Physics Laboratory (JHU/APL). Her experience includes seeker testing,
analysis of laboratory and flight data from seeker tests, and generating models of the test results. In addition, She has been a member of SPIE for several years.

Mr. Daniel Prendergast is a Senior Electrical Engineer in the Electro-Optics Group of the Johns Hopkins University / Applied Physics Laboratory (JHU / APL). He has been at JHU / APL since 1985 and works primarily with the testing and calibration of infrared sensors. In addition, He is a member of SPIE and has published in SPIE proceedings.

References